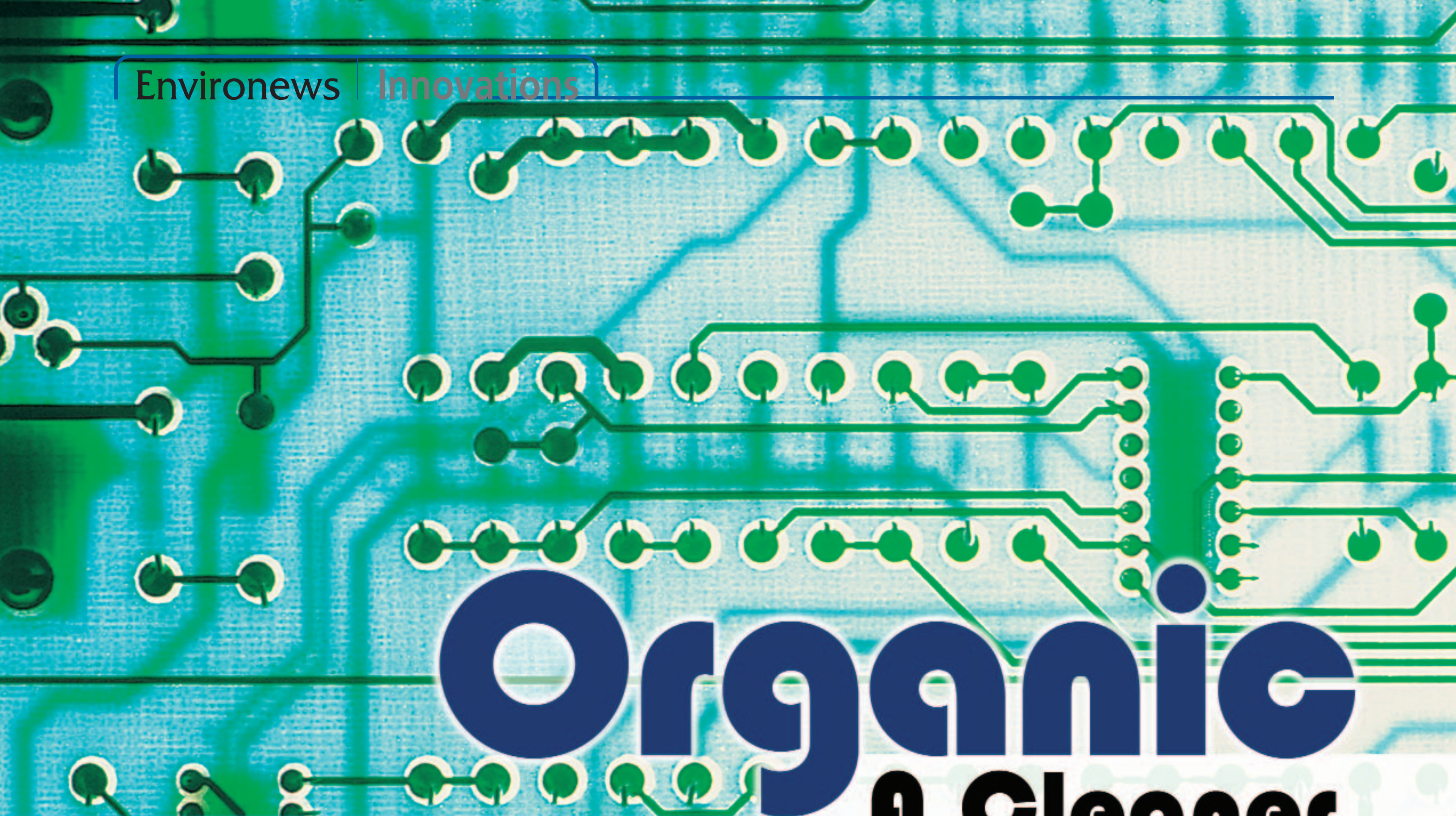


Organic
A Cleaner

Until recently, plastics—ubiquitous in most areas of modern life—had yet to make inroads into the electronics industry; their molecular configuration made them nonconducive to electrical flow, limiting their uses to shells for computers and insulation for wires. But the last few years have brought discoveries that plastic polymers can be manipulated so they may be fashioned into transistors, conductors, and other electrical components. Such uses for these carbon/hydrogen/oxygen-based polymers are the subject of the field of organic electronics.

"This is a rapidly developing industry," says Michael Schen, group leader of the Electronics and Photonics Group of the National Institute of Standards and Technology Advanced Technology Program. "We are hearing about a wide variety of potential applications, [including] transistors, electronic circuits, high-density energy storage devices, advanced emissive displays, and advanced photovoltaics." And the benefits of plastics are substantial—in many cases, researchers are finding they offer a safer, cheaper, lighter alternative to silicon.

Safer, Cheaper, Lighter

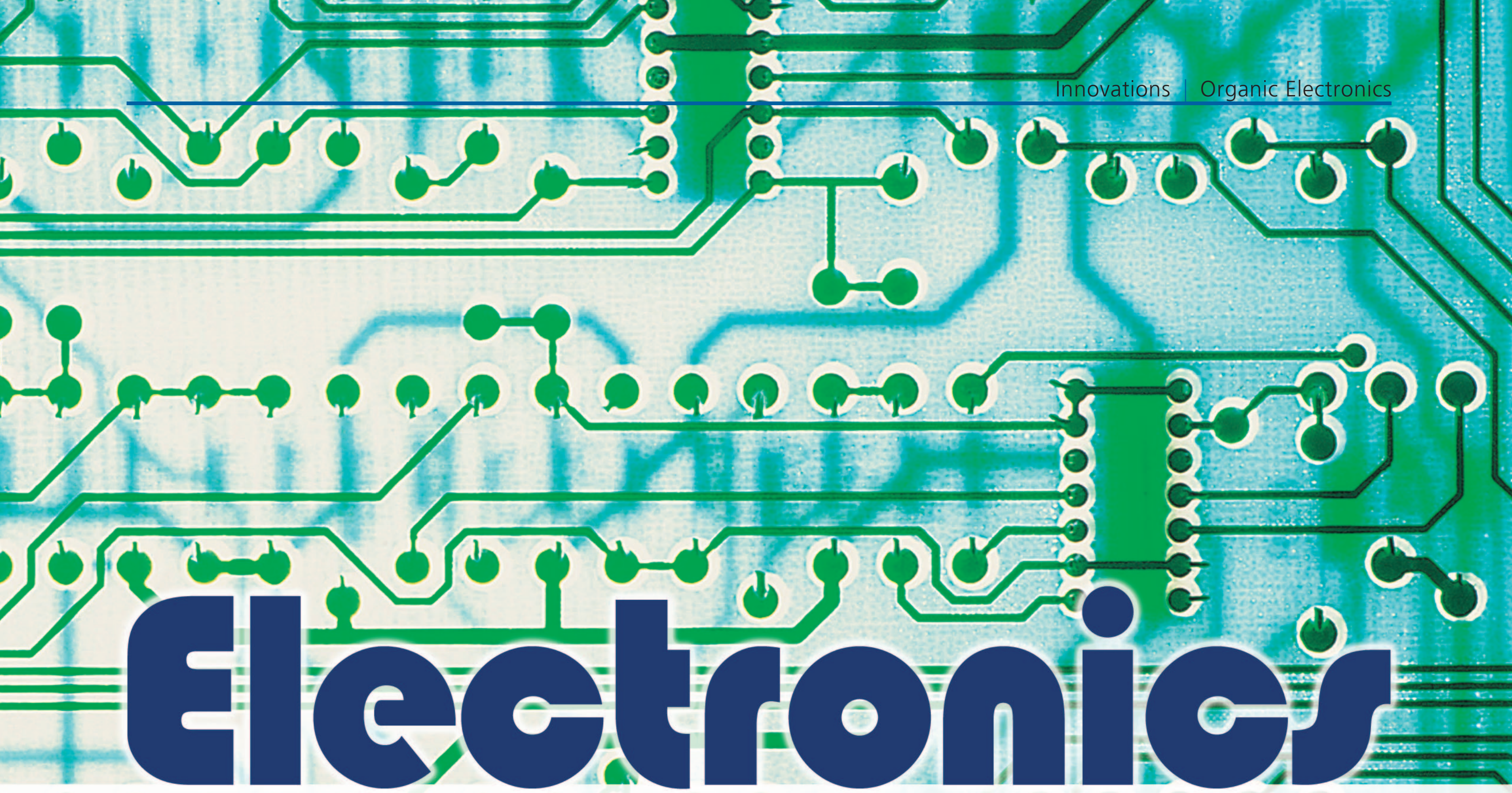
Schen says organic electronics involves a much smaller set of hazardous compounds and materials than more traditional technologies. Gone are the arsenic (used in semiconductor manufacture), phosphine (used in transistor manufacture), lead (used in the phosphorescent coating in a traditional cathode ray tube, or CRT), and mercury (used in backlights).

Silicon and silicon-based components require millions of gallons of water and temperatures of 300–500°C to manufacture. A wide range of solvents are used in silicon and in semiconductor manufacture, including highly toxic xylene and toluene. The semiconductor industry uses hundreds of thousands of gallons of such solvents annually.

In contrast, says Stewart Hough, vice president of business development for Cambridge Display Technology, his company can create components at atmospheric pressure, and at temperatures of no more than 150°C. And, although the company does use solvents with its organic technology, "we can make ten thousand displays with one liter of standard organic solvent," he says. Furthermore, says Bernard Kippelen, an associate professor of optical sciences at the University of Arizona Optical Sciences Center, it may be possible to design organics that are soluble in less harmful solvents.

Polymers also are lighter and can cost much less to manufacture, although cost comparisons vary. Kippelen says his center's deposition machine is capable, after adaptation, of applying multilayer metal and organic layers as thin as 10 nanometers to a flexible plastic substrate at a cost approaching 1¢ per square centimeter (compared to a dollar or so to produce a square centimeter of silicon substrate). "Organic fabrication is compatible with

Digital Vision, Christopher G. Reuther/EHP



Electronics

Substitute for Silicon

plastic substrates, which means you can use a very low-cost . . . substrate," he says. "Additionally, organics are good for large-area needs. For example, if you need a piece of silicon for a fingerprint recognition device, that one-square-centimeter piece of highly purified silicon"—which is quite large in terms of ultrapure silicon usage—"will be very expensive."

According to Kippelen, an organic photovoltaic cell could weigh 100 times less than a silicon-based cell. And, he says, "the promise with organics is related to the lower cost of the raw materials, in particular the substrate on which the device is built—a silicon wafer is more expensive than a sheet of plastic."

Experts generally concede that polymers won't be replacing silicon in certain applications, such as computer semiconductors, because silicon will always be significantly faster. However, plastics can serve as a substitute in applications where silicon is either impractical or too expensive to use. And improvements are on the way. "The technology is admittedly not at the same stage of maturity as something like LCD [liquid crystal display] technology, but this is a technology with great promise," Hough says.

Plastic Energy

Picture a system that automatically tracks and records each item selected as a shopper moves through a market, beaming that information to a checkout stand terminal so the bill is waiting when the customer arrives. To build such a system, you'd want to tag each item with something lightweight, flexible, durable, and cheap—something a lot like an organic "chip."

Although implementing such a scenario is still some ways away, Kippelen says organics would be ideal in the current technology of photovoltaic cells, most of which now use silicon. The lightness of organic photovoltaics would make them perfect for consumer applications such as recharging personal digital assistants, he says, and their low cost would suit them for power generation in remote villages in developing countries.

One primary goal for researchers is to increase the efficiency of the organic photovoltaic cell to a level competitive with silicon. Kippelen says the key is looking at the mechanism by which electrons are transported through the film. "Think of it like a basketball player, standing still," he explains. "If you throw him the ball, he bends to catch it, [then] bends [again] to throw it onward. The molecule in the polymer goes through the same sort of deformation when a charge hits it. The goal is to minimize what's called 'trapping time,' like having the ball just bounce from one player to another without having to go through the catch-and-throw process."

Michael McGehee is an assistant professor in Stanford University's Department of Materials Science and Engineering who has been working in the area of organic photovoltaic cells. He has developed an approach that involves mixing concentrated hydrochloric acid with titanium ethoxide, ethanol, and Pluronic® P123 (a block copolymer surfactant manufactured by BASF) to create a mesoporous titania film (the "meso-" prefix refers to pores of 2–50 nanometers in diameter). He dip-coats the substrate with the titania mixture, then treats it to remove the block copolymer and densify the titania.

The process is still in development, so McGehee is understandably guarded about what he's accomplished, but he believes there's tremendous promise for several reasons. "For one thing, you can do the deposition at atmospheric pressure [which reduces the cost of the process]," he says. "And polymers are cheap and nontoxic, while high-quality crystalline silicon is decidedly not cheap. Our goal is to be able to do this on sheets of plastic, where you just roll it through a coater and drop the coating on the substrate."

McGehee says most crystalline silicon photovoltaic cells have an energy conversion efficiency of 12% and a cost per square meter of $300.00 (equivalent to $3.50 per watt of power generated in peak sunlight). He says it will be important to raise the energy conversion efficiency of organic photovoltaic cells from their current 3.5% to 8–12%, while providing a 10- to 20-year life span and reducing their cost by a factor of 10, to 50¢ per watt to generate. Manufacturing technologies must evolve to the point that they can achieve the desired cost reduction, something that many experts estimate will take 5–10 years.

On the Line

Organic photonics is another rapidly growing technology that takes advantage of plastics' unique properties—think emission of photons, rather than electrons. Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation, to detection, to communications and information processing.

With the increasing use of fiber-optic technology, communications and data transmission have reached speeds unheard of only a few years ago. But most fiber-optic lines still end short of residential users; the majority of homes still have old-fashioned copper wiring, and the signal slows dramatically when it hits that copper wire.

Plus, there's another bottleneck. Switching the signal from electrical to optical requires a device known as an electro-optic modulator. Currently, those modulators are made of a specially grown crystal known as lithium niobate, a stable substance (with a melting point over 1,200°C), but one that has three main disadvantages: it can't be switched faster than a few billion times a second, it takes as much as 6 volts to operate (thus consuming a lot of power and generating a lot of heat), and it can't be incorporated directly onto integrated circuit chips. That means it must somehow be connected to the integrated circuit chip, adding another possible source of signal degradation and power consumption—not to mention making the manufacturing process more involved.

A team led by Larry Dalton, a professor of chemistry at the University of Washington in Seattle, has developed a new organic modulator consisting of chromophores (molecules that absorb incoming light and emit a colored glow) embedded in a polymer base. This modulator requires as little as 0.8 volts to operate and can switch at up to 110 billion times a second.

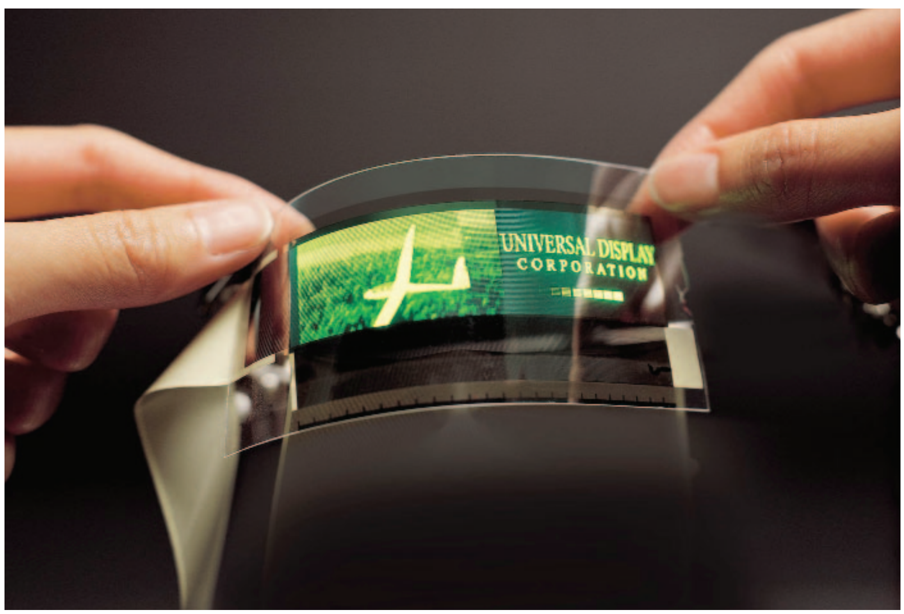
"What we've done," says Dalton, "is to exploit the best of electronics and photonics in one package." Electro-optics does not compete with fiber optics or wireless communication, he says, but rather permits the large bandwidth capability of those technologies to be integrated with the fastest electronic technologies. In short, electro-optic materials and devices permit information to be converted between the electronic and photonic domains at tremendous speeds—terahertz capabilities, compared with current capabilities of at most a few gigahertz.

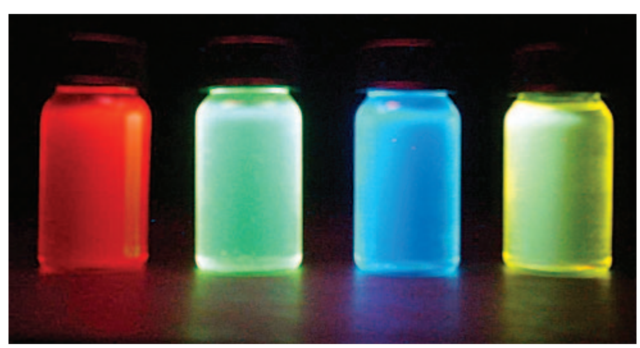
With organic electro-optic materials, Dalton says, all of the circuit processing is dry, using oxygen-reactive etching and photolithography, thus dramatically decreasing solvent usage. "The only aspects that have any environmental impact are associated with [solvent use in] steps such as electrode deposition and mask fabrication," he explains. "These problems exist for any materials technology, including lithium niobate."

Extensive laboratory testing suggests the new modulating devices could attain 10-year lifetimes, says Tom Mino, CEO of Lumera Corporation, a Bothell, Washington–based company working to commercialize the research of Dalton and others. "This technology is cheaper to manufacture, it's more environmentally benign, and it reduces power requirements in usage," Mino says. But, as with many new technologies, one key will be development of the market with systems suppliers such as Cisco, Alcatel, and Nortel—companies that will be using the new technology in actual communications systems in a market that could approach several billion dollars annually.

Shedding Some Light

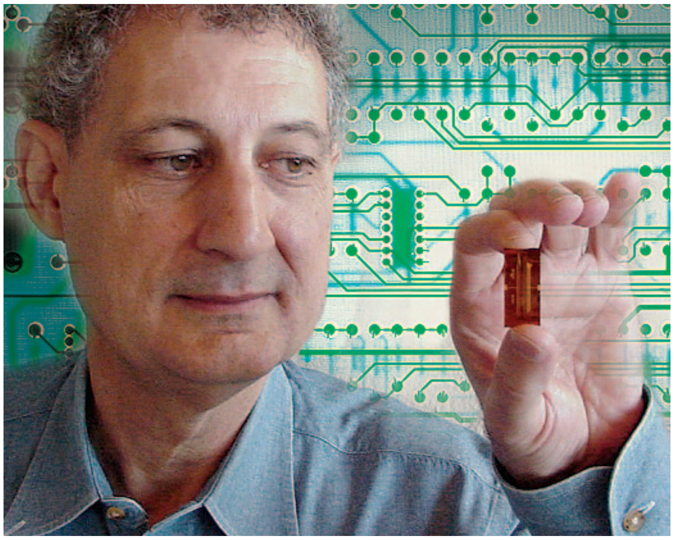
Although computers may not yet be using organic electronics, their monitors now can. Organic light-emitting devices, or OLEDs, operate by accepting charge carriers of opposite polarities—electrons and holes—from cathode and anode contacts, respectively. An externally applied voltage drives these carriers into a recombination





Bending light. Universal Display Corporation's flexible organic light-emitting device (above) is made with technology that enables very thin, impact-resistant displays that are conformable to contoured surfaces and can be repetitively flexed. Light emitting polymers (right) are the raw materials used in Cambridge Display Technology color displays.

Top to bottom: Universal Display Corporation; Cambridge Display Technology



Solving the solvent problem. Chemist Larry Dalton of the University of Washington in Seattle holds a polymeric "opto-chip" made with a dry process that dramatically reduces solvent usage.

Larry Dalton, Christopher G. Reuther/EHP

region, where they form a single neutral bound state known as an exciton. Two types of excitons are formed: singlets and triplets.

In conventional fluorescent OLEDs, light emission occurs as a result of the recombination of singlet excitons, and the internal quantum efficiency is limited to approximately 25%. In phosphorescent OLED devices, all excitons may be converted into triplet states through intersystem crossing around a heavy metal atom. These triplet states emit radiatively, enabling extremely high efficiencies. Universal Display Corporation, a New Jersey–based research and development firm, has teamed with researchers at Princeton University and the University of Southern California to develop this technology and have demonstrated devices with internal efficiencies approaching 100% and record-breaking power efficiencies.

Universal is working on the technology to build organic flat panel displays that are lightweight, portable, even rollable. Janice Mahon, vice president of technology commercialization for Universal, explains that a typical LCD consists of two pieces of glass with liquid crystals sandwiched between, plus a color filter and a fluorescent backlight. "Dopants" are added to the host material to modify and enhance its electrical properties. By comparison, the Universal OLED consists of a 3,000- to 5,000-angstrom-thick layer of thin films deposited on a single glass substrate. She estimates that the Universal OLED saves as much as 50% in material content. Furthermore, whereas the typical LCD requires an estimated 200 or so processing steps, the Universal OLED takes about 86. "Moreover," says Mahon, "it is conceivable to take an existing LCD [manufacturing] facility, take out about thirty percent of the process machinery, replace half of that, and use the same facility for OLED fabrication."

According to Mahon, Universal's OLED technology does not use hazardous materials like those used in inorganic light-emitting device production. But the environmental benefit goes far beyond that. "Our technology translates into a display that—used in a laptop, for example—could consume as little as fifty percent of the power of a typical LCD display," she says. "And with continued improvements in technology, we could get as low as twenty-five percent of the power."

Mahon says that some of the dopants her company has developed may typically contain trace amounts (less than 1% of the total volume) of heavy metals such as iridium or platinum, substances far more environmentally benign than the lead, mercury, and other elements that can make disposal of CRTs so problematic.

The most significant challenge in developing the materials for these OLEDs, she says, is to reach the high state of purity needed, which she describes as similar to that of pharmaceutical chemicals. "Purity is critical in the light efficiency of the display, the color emitted, and the lifetime of the resulting device," she says. "If you have impurities, they can lead to side reactions, which can cause degradation to occur, impacting the function and lifetime of the device."

Although Universal focuses on research and development, Mahon says the company has relationships with a number of companies working on commercialization of products using this technology. "OLED technology is still very much in a start-up phase," she admits. "But we think it's a technology with a tremendous future."

A Bright Future

Schen says all organic electronic and photonic technologies will benefit from continued progress in creating materials and devices with longer lifetimes. "We've seen significant incremental increases, but as the industry continues to show it can achieve products with good lifetimes, that will in turn open up lower-cost manufacturing processes," he says. Another target is the continued development and demonstration of a technology that doesn't require the super-clean environment of existing semiconductor and flat panel display manufacturing facilities. Eventually, Schen says, "we'll see a jettisoning of some of the more expensive, riskier manufacturing processes and the broad appearance of products using organic or flexible electronics."

Schen further sees organic electronics as an equal-opportunity field. "As the industry continues to develop, it will be through a combination of large, well-funded companies, and smaller, more nimble, and innovative firms," he says. "Five years from now, I think we'll be astonished at what this industry has become."

Lance Frazer

Suggested Reading

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